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THE USE OF A HELIUM MASS SPECTROMETER LEAK DETECTOR

by Earle W. Young

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SUMMARY

26091

This document describes some fundamental theoretical and practical applications of the helium mass spectrometer leak detector in relation to vacuum chambers and particularly to items to be leak checked inside vacuum chambers. Of the three basic methods of leak detection—pressure testing, vacuum testing, and pressure-vacuum testing—only the latter is treated extensively. The leak detector output is derived as a function of the pressure of the helium or helium mixture behind the leak, as a function of helium concentration, and as a function of time. The results are discussed both quantitatively and qualitatively.

author

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INTRODUCTION

Often spacecraft or spacecraft components have "built-in atmospheres." This provision is required to alleviate particular problems. When mechanical motions in a hard vacuum are involved, lubrication difficulties and the possibility of cold welding exist. If a spacecraft is designed to measure ambient pressure or gas constituents, the contamination of the instruments due to the outgassing and sublimation of the surrounding components would lead to erroneous data. For long term flights, a sealed spacecraft must be leak tight to avoid storing large quantities of liquid gases to be used for maintenance of internal pressure.

To insure the required integrity, it must be possible to describe extremely small leak rates accurately. The mass spectrometer leak detector is the most sensitive and accurate instrument in use for determining quantitative leak rates. Helium is the most frequently used tracer gas for leak detection.

A glossary of definitions used in leak detection work is given in Appendix A.

A leak rate is usually defined in either micron cubic feet per unit time, or standard (sometimes atmospheric) cubic centimeters per unit time. A micron cubic foot is the quantity of gas that will raise the pressure 1μ if introduced in a 1 ft^3 container when the temperature is 0°C. A std cm^3 is the mass contained in a cube of 1 cm dimensions at 1 atmosphere pressure and 0°C. The units of std cm^3/sec are the ones most frequently used.

The leak detector, by virtue of the mass spectrometer principle, continuously measures the partial pressure of helium at the sensing element. The instrument's sensitivity, then, can be defined as the smallest helium partial pressure at the source that will give a readable output. The readable output is arbitrarily set at 5 divisions on the most sensitive scale (×1 attenuation). Amplifier noise and other disturbances will cause fluctuations of approximately 3 divisions.

Leak detector manufacturers also make specifications for sensitivity. Typical specifications are:

1. The smallest detectable helium concentration in air at a specified source pressure.

2. The smallest pure helium leak which can be detected at a specified source pressure under the test conditions.

Specification 1 indicates that the leak detector source and electronics are designed to give a readable output for an extremely small helium partial pressure. The rate of flow of a helium-air mixture may vary; yet the output will remain constant if the helium partial pressure remains constant. Units of sensitivity in this case are helium partial pressure (in μ or mm of Hg) per division on the output meter. Once assigned, this value remains essentially constant. The only factors that will change it are contamination or aging of the source or instability in the electronics. Specification 2 indicates that the leak detector will give a readable output for an extremely small pure helium leak *rate*. In order to read the smallest possible leak rate it is important to analyze system parameters such as inbleed, outgassing, and the speed of the vacuum pumps. Units of sensitivity in this case are helium flow rate (usually std cm^3/sec) per division on the output meter. The important point to note here is that sensitivity is a function of the helium flow rate and, as such, may vary from test to test.

METHODS OF LEAK DETECTION

There are three general methods of leak detection—pressure testing, vacuum testing, and pressure-vacuum testing. The first two will be discussed only briefly. The third method is essentially the subject of this paper.

In the *pressure testing* method (Figure 1) the item to be leak checked is pressurized with helium. Suspected areas of leakage are then probed by a "sniffer." The escaping helium is pumped into the leak detector through a very small aperture in the sniffer. Small leaks, of the order of 10^{-7} std cm^3/sec and smaller, cannot be detected by this method since the escaping helium is diluted by the surrounding air.

In the *vacuum testing* method (Figure 2) the item to be leak checked is evacuated by means of an auxiliary pump. The auxiliary pump is then valved out and the leak detector is valved in. Suspected areas of leakage are sprayed with helium. The helium is pumped through the leak into the leak detector, and the output is recorded. Much smaller leaks can be found by this method than by the pressure testing method.

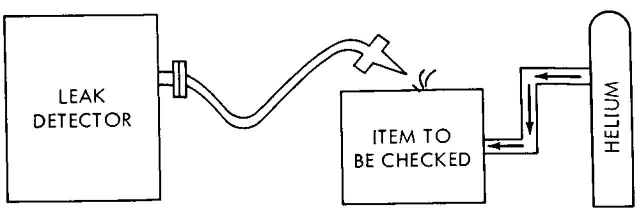

Figure 1—The pressure testing method.

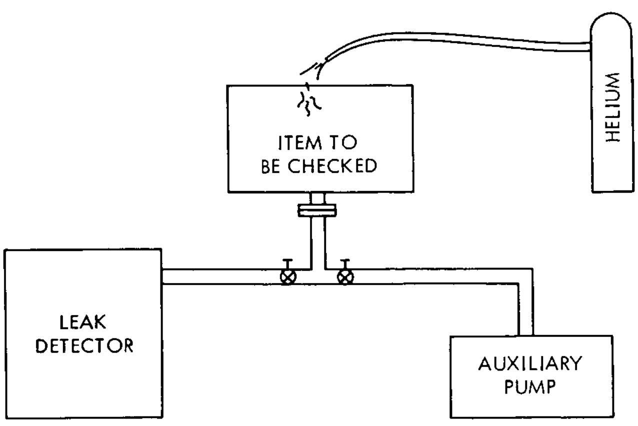

Figure 2—The vacuum testing method.

In the *pressure-vacuum* method the item to be leak checked is filled with helium or a mixture of helium and some other gas. It may or may not be pressurized. It is placed in a vacuum vessel which is evacuated by auxiliary pumps. The leak detector may be connected to the vacuum chamber directly as shown in Figure 3, or to the foreline as shown in Figure 4. After the vessel has been evacuated sufficiently by the auxiliary pumps, the inlet throttle valve on the leak detector is opened and output-time data are taken, with zero as the time of the opening of the inlet throttle valve.

The leak detector output varies with the helium flow rate, which varies with test conditions and the geometry of the leak. A known leak gives an output which depends on the helium concentration entering the leak as well as the working pressure of the helium or helium mixture. When the vacuum method or pressure-vacuum method of leak detection is employed, the output is a function of time as well as concentration and working pressure. This is because a test system having large volumes or high impedance piping also has long delays in response due to the time required for the helium concentration to build up in the leak detector.

The following discussion will assume a gas flow through a leak with atmospheric pressure on one side and a vacuum on the other. The flow is viscous, transitional, or molecular, depending on the mean free path of the molecule and the length of the cross-section in which it is contained. If the flow is viscous, it follows Poiseuille's Law for viscous flow:

$$Q = \frac{Cd^4}{L\eta}\left(p_1^2 - p_2^2\right),$$

where

Q = flow rate in pressure-volume units,
C = a constant,
d = diameter of pipe,

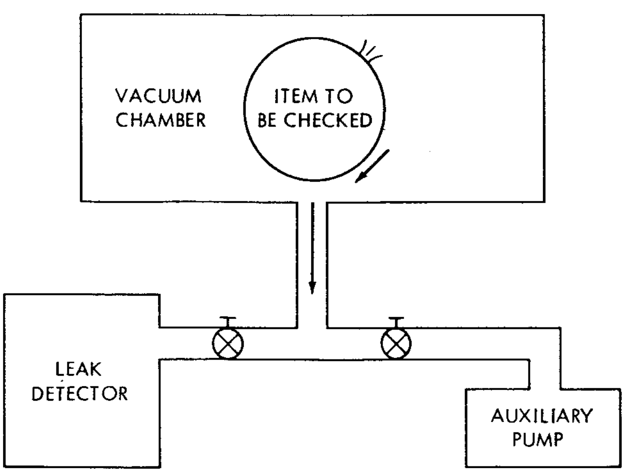

Figure 3—Chamber connection for the pressure-vacuum testing method.

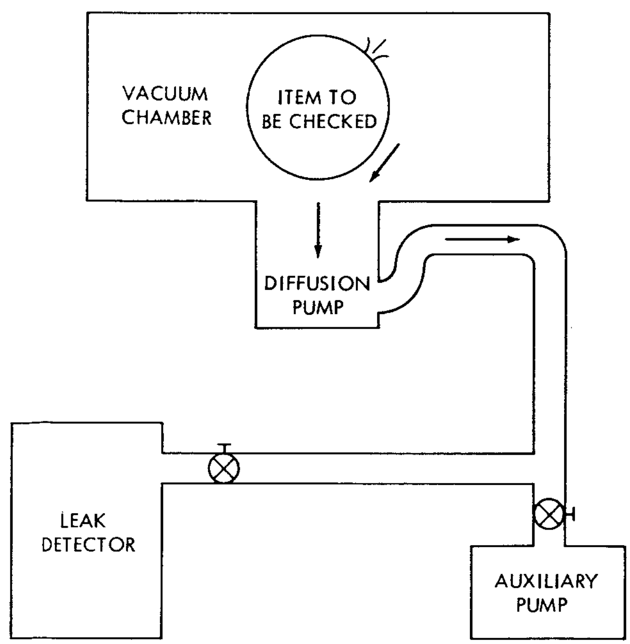

Figure 4—Forearm connection for the pressure-vacuum testing method.

L = length of pipe,
η = viscosity of the gas,
p_1 = upstream pressure,
p_2 = downstream pressure.

If the flow is molecular, it follows Knudsen's Law for free molecule flow:

$$Q = \frac{K\,d^3}{L\,\sqrt{M}}\left(p_1 - p_2\right),$$

where

K = a constant,
M = molecular weight of the gas.

Transitional flow is not considered here for reasons that will become apparent. The important points to note are:

1. The flow rate varies directly with the diameter and inversely with the length in both viscous and molecular flow.

2. For viscous flow, the flow rate varies inversely with viscosity and directly with the difference of the pressures squared.

3. For molecular flow, the flow rate varies inversely with the square root of the molecular weight and directly with the difference in pressure.

4. In both viscous and molecular flow p_2 may be considered zero when the leak is under vacuum on one side.

For a given *unknown* leak it is impossible to define the diameter of the leak or its length. It is possible to say that at the vacuum end molecular flow exists (for helium at 1μ pressure and room temperature, the mean free path is approximately 14.7 cm). This then is all that is required to approximate changes in the flow rate of a given gas to changes in concentration or pressure. The story is quite different in trying to relate the flow of different gases through a given leak. Here the flow patterns must be accurately known. Since this is subject for a complete study of its own, it will be dogmatically stated that experience has shown that leaks larger than 10^{-6} std cm^3/sec are essentially viscous in nature and those smaller than 10^{-8} std cm^3/sec are essentially molecular in nature.

Output as a Function of Pressure

For a given leak, Knudsen's Law states that the flow rate is directly proportional to pressure. Since the flow rate is also directly proportional to the leak detector output, the output is proportional to pressure. The output with 1 atmosphere differential across a leak will approximately double when 2 atmospheres are applied to the same leak. This effect is illustrated by a laboratory experiment described in Appendix B. The deviation from a direct proportionality is due to changes in flow patterns, surface phenomena, and changes in the geometry of the leak. Sufficiently accurate results can be obtained if the relationship is considered to be a direct one. All other system parameters, especially source pressure, should remain unchanged.

Output as a Function of Concentration

The helium partial pressure behind the leak is directly proportional to the helium concentration. The detector output is directly proportional to this partial pressure and therefore proportional to the helium concentration. If the helium concentration is halved, the partial pressure is halved and the output is approximately halved. Again, all other system parameters must remain unchanged. As the helium concentration is reduced to a lower and lower level, the deviation of the proportional relation between the detector output and concentration increases. This is due to the fact that concentration is not constant on both sides of the leak because of changes in flow patterns. When the mixture is largely helium, sufficiently accurate results are obtained by using the direct relationship.

Pressurizing and changing concentration are useful in testing extremely large systems for economic reasons. When precision in determining the actual size of the leak is critical, the item should be leak checked at its maximum expected working pressure and concentration. With any further increase in pressure or reduction in concentration, increase in output and sensitivity are far outweighed by the problems which are built in.

Output as a Function of Time

To leak check a system accurately and expeditiously, it is of the utmost importance for the system to react as rapidly as possible when the tracer gas is applied to a leak. That is, the system must have a short *response time*. It is equally important that the system rid itself of the tracer gas when it is removed from the leak. That is, the system must have a short *cleanup time*. Of course, the response and cleanup times are characteristics of the system as a whole. This includes the test object (whether it be the vessel itself or a leaking test item inside the vessel), the auxiliary pumps, the interconnecting pipe work, and the leak detector. Any leak detector will respond almost immediately to changes in helium concentration that occur at the inlet throttle valve.

Basically the system reacts as follows: When helium is applied to a leak, the helium concentration rises and therefore the helium partial pressure rises. The leak detector, by virtue of the mass spectrometer principle, reacts to a change in helium partial pressure. For any given vacuum system the rate of change of helium partial pressure may be described as follows:

$$\frac{dp}{dt} = \frac{Sp}{V} , \qquad (1)$$

where

p = partial pressure of helium in the test space,
S = system pumping speed at the entrance to the test space,
V = volume of the test space.

With small pressure increments the speed of the system is constant, and the solution to Equation 1 is:

$$t = \frac{V}{S} \ln \frac{p_2}{p_1} . \tag{2}$$

Equation 2 may be simplified by appropriate definitions of the response and cleanup times.

Cleanup time is the time required, when no source of helium is present, for the leak detector output to be reduced to $1/e$ (or 37 percent) of its initial value. In this case $p_1 = 0.37\ p_2$ and $\ln(p_2/p_1) = 1$. Therefore Equation 2 reduces to

$$t = \frac{V}{S} . \tag{3}$$

Response time is the time required for the leak detector to yield an output equal to $1 - (1/e)$ (or 63 percent) of the maximum obtainable signal when the tracer gas is applied indefinitely to the system under test. In this case

$$p_2 = 0.63\ p_{max} ,$$

$$p_1 = 0.37\ p_2 = 0.233\ p_{max} ,$$

$$\ln \frac{p_2}{p_1} = 1 ,$$

and again Equation 2 reduces to $t = V/S$.

A graphical presentation will now be discussed to clarify further what has been said. Figure 5 shows the plot of helium partial pressure vs. time on a semilog base. During the first portion of the curve there is no source of helium present and therefore the helium partial pressure is being reduced from p_2 to p_1 because of the inherent system pumping action. The time lapse between p_2 and p_1, when $p_1 = 0.37\ p_2$, is 1 time constant and is described by Equation 3.

A constant source of helium is then applied to the system; the helium partial pressure will rise from $p_{ultimate}$ to p_{max}. Again the time lapse between p_1 and p_2 is 1 time constant, if $p_2 = 0.63\ p_{max}$, and is described by Equation 3.

Time constants (response and cleanup times) may vary from seconds to hours, depending upon the size and configuration of the pumping system and its pumping capacity. An illustration of output vs. time is included in Appendix B.

Figure 6 is a plot of the percent of total response vs. the time constant multiplier. In a given system the time constant may be computed by using Equation 3. With this and Figure 5 the percent of total leak at any given time can be predicted accurately. Figure 6 is constructed as follows: It has been shown that at 1 time constant, 63 percent of the maximum deflection for a given leak is obtained. To achieve 90 percent of the maximum deflection, p_2 in Equation 3 must be 90 percent of p_{max}. Therefore

$$\frac{p_2}{p_1} = 10 ,$$

$$\ln \frac{p_2}{p_1} = 2.3 ,$$

and it will take 2.3 time constants to yield 90 percent of the maximum output.

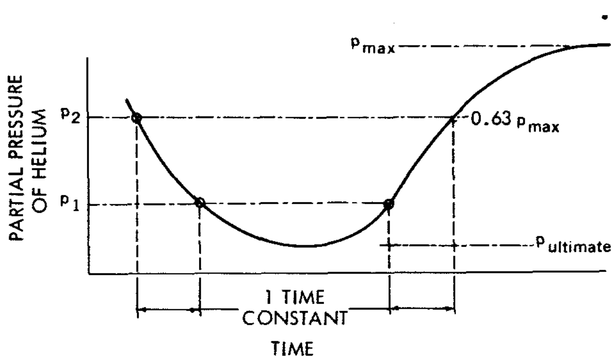

Figure 5—Helium partial pressure (on a logarithmic scale) vs. time (on a linear scale).

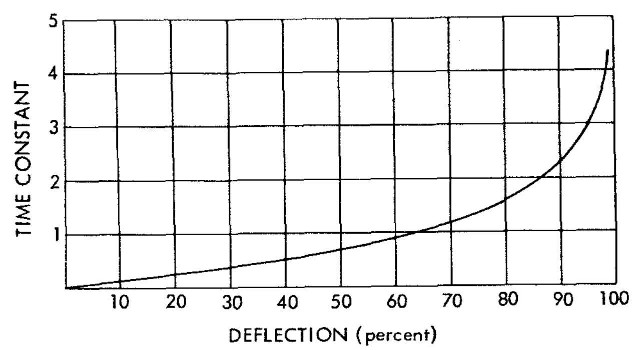

Figure 6—Percent of total response vs. the time constant multiplier.

The discussion thus far has been of a preliminary nature. Further study is required for the precise measurement of the flow of gases through leaks. Some of the points that merit study are:

1. Flow pattern in relation to leak magnitude.

2. Relationships governing the flow of various gases through leaks as a function of leak magnitude.

CONCLUSIONS AND RECOMMENDATIONS

To define a leak quantitatively it is necessary to know:

1. The output of the leak detector in divisions, and the time, after starting, that the output was taken. Time zero is the instant the sensing element is exposed to the tracer gas.

2. The sensitivity of the leak detector.

3. The response of the system as a function of time. The system includes the leak detector, interconnecting lines, the vacuum vessel, and any auxiliary pumping that is used.

Good qualitative results can be obtained by setting up the equipment properly and avoiding some common pitfalls associated with leak detection. A few points that merit attention will be discussed:

Location of the Leak Detector in the Vacuum System

Large vacuum vessels are usually evacuated by a high speed oil diffusion pump(s) backed by mechanical pumping. In this case the leak detector is connected to the foreline where the pressure is higher than in the leak detector. This assures some flow of the sample gas to the leak detector. Essentially all of the sample gas will flow to the leak detector if the mechanical pump is valved out. The effect here is to back the high speed diffusion pump with the pumping system in the leak detector. This must be done in intervals of short duration, however, since the pumping system in the leak detector often does not have adequate capacity to back large diffusion pumps. Results of insufficient backing are a rise in vessel pressure, deterioration of the pump oil, and an increase in the backstreaming rate.

If the inbleed and gas load are small, the pumping system in the leak detector may be capable of maintaining a low pressure in the vessel with all the auxiliary pumps valved out. The instrument may then be connected directly to the vessel. Here again the operator is assured that the largest possible amount of the sample gas is passing through the leak detector.

In either case auxiliary pumping must be used piror to valving the leak detector into the system.

Extraneous Sources of the Tracer Gas

Excessive amounts of rubber, for example, gaskets and rubber tubing, should not be used since they absorb helium. When a large leak is encountered, appreciable amounts of helium are absorbed by the rubber and will then give false leak indications on succeeding tests.

Lubricants and vacuum greases should be avoided also, since they too have an affinity for helium. Good vacuum seals are obtainable without the use of greases. In addition, greases are dirt catchers and as such will contaminate the vacuum system.

Helium Background

If a large leak is encountered the entire system may become saturated with helium. This background level may then remain large enough to overcome smaller leak indications on succeeding tests. High background levels may be overcome by "flushing" the system, i.e., continuously pumping while dry air or nitrogen is admitted to the vessel. As has been mentioned previously, other sources of helium are greases and rubber.

The following is a useful rule of thumb: As the magnitude of the leak being sought becomes smaller and smaller, the helium background level becomes more and more important. Hence, background levels should always be checked before and after a test, and calculations adjusted accordingly.

Proper Connection of the Leak Detector to the System

The criterion here is to connect the leak detector to the test system so that the inlet throttle valve on the leak detector may be fully opened and the largest possible amount of sample gas admitted to the leak detector. Maximum tolerable pressure levels in the leak detector and test system as well as the size of interconnecting lines will determine this.

Often the auxiliary pumping system cannot be valved out. If this is the case the pumping of the auxiliary pump will rob the leak detector of a large portion of the tracer gas. The amount of flow to the leak detector and auxiliary pump is proportional to their effective speeds at a common intersection point in the overall system.

Correct Calibration of the System

Prior to any leak checking, the leak detector must be calibrated. This is done by recording the output of the detector to a known leak. The magnitude of the known leak divided by the output will give the calibration in flow rate per division of the output meter. Note that most precalibrated standard leaks are temperature sensitive. If this is the case use the corrected leak rate for the ambient temperature at the time of calibration.

Always calibrate the leak detector by locating the known leak in a position that will simulate actual test conditions. If the object to be tested will be located immediately adjacent to the inlet throttle valve, calibrate by placing the known leak in that position. If the object to be tested is a vacuum chamber or an object to be located in a vacuum chamber, and the leak detector will be connected to the foreline, calibrate by locating the known leak in a representative position in the vacuum chamber. In this case output vs. time must be known. When using glass standard leaks, and the leak is to be placed inside a vacuum chamber, the helium diffusion through the glass envelope as well as that through the quartz membrane must be considered. The rate given by the manufacturer is for helium diffusion through the quartz membrane only.

Remember that when a system is calibrated by using a pure helium leak with 1 atmosphere pressure differential across it, the rate obtained during an actual test must be that for pure helium across 1 atmosphere pressure differential. If, in the actual test, the helium is reduced in concentration by being mixed with another gas or increased in pressure, the calibration will have to be adjusted accordingly. The example in Appendix B will demonstrate this.

(Manuscript received January 2, 1963)

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Appendix A

Glossary of Definitions

Some of the terms used in leak detection are included below.

1. *Background* – the spurious output due to the response to other gases including the tracer gas which may be trapped in the vacuum system.
2. *Base sensitivity* – the sensitivity computed with a standard leak in mass flow per unit time per division output.
3. *Cleanup time* – the time required for the output to be reduced to 37% of its initial value when the source of the tracer gas is removed.
4. *Leak rate* – the rate of flow of a gas through a leak from a specified high pressure (usually 1 atmosphere) to a pressure which is low enough to have a negligible effect on the rate of flow.
5. *Mean free path* – the average distance a molecule travels between collisions with another molecule.
6. *Minimum detectable leak* – the magnitude of the smallest leak that is distinguishable from the noise level and background.
7. *Molecular flow* – the type of flow characterized by a gas in which the mean free path is very large compared to the largest dimension of the container in which it is housed.
8. *Noise level* – the spurious output due to sources other than the tracer gas.
9. *Outgassing* – the spontaneous evolution of gas from materials in a vacuum system.
10. *Output* – A leak indication read in divisions on a linear scale. A stepping switch is usually incorporated which provides attenuations of this scale.
11. *Permeability* – the steady-state rate of flow of gas through a unit area of unit thickness of a solid barrier per unit pressure differential at a given temperature.
12. *Relative sensitivity* – the ratio of the base sensitivity of a pure helium standard leak to that of reduced concentration, increased pressure, or both.
13. *Response time* – the time required for the system to yield an output of 63 percent of the maximum signal attained when the tracer gas is applied indefinitely to the system under test.
14. *Sensitivity* – the smallest helium partial pressure that will give a readable output.
15. *Source pressure* – the pressure at the leak detector sensing element.
16. *Standard leak* – a device which permits leakage of a specified gas, at a specified rate, with atmospheric pressure at one end and a pressure low enough to have negligible effect on the leak rate at the other.

17. *Transition flow* – flow intermediate between viscous and molecular.

18. *Virtual leak* – (1) the evolution of gas from a cold surface on which the gas had previously condensed at higher pressures or lower temperatures; (2) the semblance of a leak in a vacuum system caused by a slow release of sorbed or occluded gas.

19. *Viscous flow* – the type of flow characterized by a gas in which the mean free path is very small compared with the smallest dimension of the container in which it is housed.

Appendix B

Output and Sensitivity vs. Pressure; Output vs. Time*

Variance of Output and Sensitivity with Pressure

To demonstrate the variance of output and sensitivity with pressure, a calibrated orifice was connected to the intake flange on the leak detector. The orifice will admit a pure helium leak rate of 3.6×10^{-6} std cm^3/sec with 1 atmosphere differential across it. The leak detector had been previously calibrated with two other known leaks and the average sensitivity taken. This was 1.5×10^{-10} std cm^3/sec per div. Pure helium at atmospheric pressure was then admitted to the orifice. The output was $2.4 \times 10^{+4}$ divisions. The helium supply pressure was then increased and the output was recorded. The data are shown on Table B1. Output vs. the absolute pressure behind the leak is plotted on Figure B1. Theory dictates that the plot be a straight line with a slope of 1, however, surface effects and changes in flow patterns show deviations. The maximum deviation in the pressure range being considered is 4 percent.

Table B1

Leak Rate vs. Absolute Pressure Behind the Leak. (Calibration: The leak detector output was 5500 divisions for a 8×10^{-7} std cm^3/sec leak and 4700 divisions for a 7.2×10^{-7} std cm^3/sec leak.)

Differential Across Leak (psia)	Output (divisions)	Source Pressure (μ)
14.7	48 × 500	0.01
17.2	55 × 500	0.01
19.7	62 × 500	0.01
24.7	78 × 500	0.01
29.7	47 × 1000	0.01
34.7	55 × 1000	0.01
39.7	64 × 1000	0.01
44.7	73 × 1000	0.01

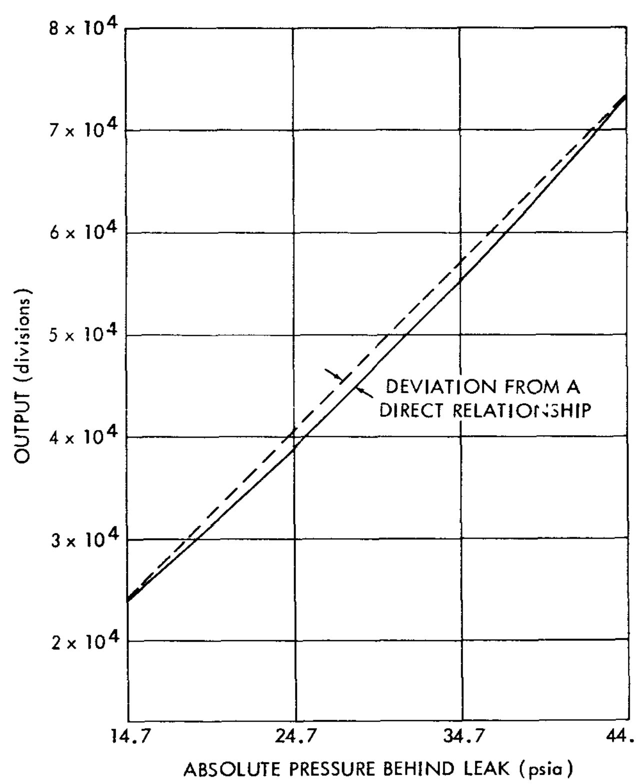

Figure B1—Detector output as a function of pressure.

*The particular detector employed was Consolidated Electrodynamics Corporation Model 24-120.

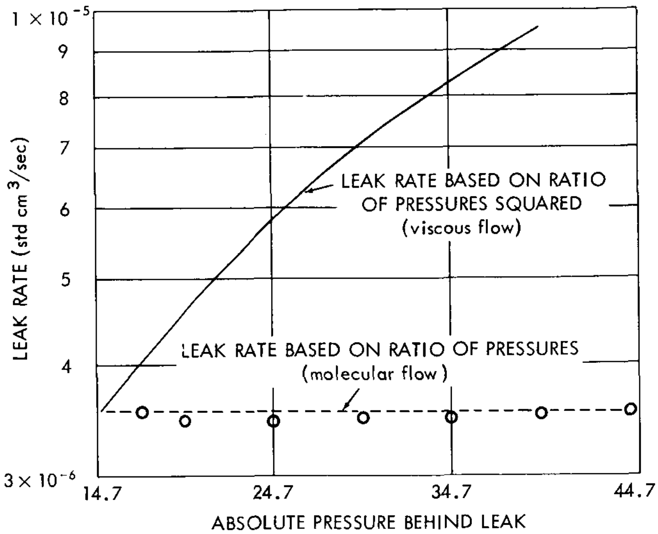

Figure B2—Variance of detector sensitivity with pressure. The actual leak rate was 3.6×10^{-6} std cm³/sec.

Figure B2 is a plot of the leak rate vs. the absolute pressure behind the leak. The plot was obtained in the following manner: The orifice will allow a mass flow rate of 3.6×10^{-6} std cm³/sec with 1 atmospheric differential across it. As the pressure is increased, the flow rate increases and output increases. At the same time, sensitivity is increasing since it, too, is a function of flow rate. The base sensitivity remains unchanged at 1.5×10^{-10} std cm³/sec per div.; however, relative sensitivity is increasing with pressure. For example, at 34.7 psia the relative sensitivity is

$$\frac{34.7}{14.7} = 236 \text{ percent} .$$

Therefore

$$\frac{S_b}{S} = 236 \text{ percent} ,$$

$$S = 5.56 \times 10^{-11} \text{ std cm}^3\text{/sec per div} .$$

The data indicate that the output was 5.5×10^4 divisions at 34.7 psia. Therefore the leak was

$$(5.56 \times 10^{-11})(5.5 \times 10^{+4}) = 3.56 \times 10^{-6} \text{ std cm}^3\text{/sec} .$$

The result obtained is the leak rate with 1 atmosphere differential across the orifice. The leak rate has been referred to atmospheric pressure. If in an actual test the working pressure of the test item is to be 34.7 psia, the leak rate would obviously be greater than the rate referred to atmospheric pressure. In this case it would be $(1.5 \times 10^{-10})(5.5 \times 10^{-4}) = 8.25 \times 10^{-6}$ std cm³/sec. The only reason for defining relative sensitivity is in the event that an actual test item is pressurized during preliminary checkout (to increase the sensitivity of the leak detector), but has a different working pressure and therefore a different leak rate.

Figure B2 also shows the leak rate based on the ratio of the pressures squared. This is merely a graphic example of what would happen under the assumption that the leak rate increased in proportion to the ratio of the pressures squared (following Poiseuille's Law for viscous flow) rather than the ratio of pressures (following Knudsen's Law for molecular flow). Flow in this case is obviously molecular.

Theoretical Output vs. Time Compared with Actual Output vs. Time

In obtaining output vs. time data, the following test was set up: The leak detector was connected to a vacuum chamber through 15 in. of 0.50 in. inside diameter line and 45 in. of 0.75 in. inside diameter line in series. The volume of the chamber was 113 ft^3. The pumping speed of the leak detector was approximately 14 liters/sec for helium at the inlet throttle valve. Also connected to the chamber was a manifold through which a pure helium leak of 8×10^{-7} std cm^3/sec could be introduced. Figure B3 is included for clarity.

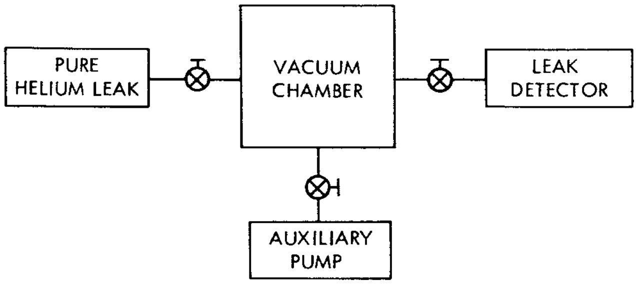

Figure B3—Equipment setup for the determination of the time constant.

The chamber was held under vacuum by the auxiliary pumping system for 24 continuous hours before the helium was introduced to minimize the wall gas load. The leak detector inlet throttle valve was opened, the auxiliary pump valved out, and the helium leak valved in, in that order. Output was then recorded with time. The data are shown on Table B2. The actual and theoretical time-division curves are shown on Figure B4.

The theoretical curve was obtained as follows: From the conductance (C) of the interconnecting pipework and the speed of the leak detector at the inlet throttle valve, the effective system

Table B2

Output as a Function of Time. (Calibration: The leak detector output was 5300 divisions for a pure helium leak of 8×10^{-7} std cm^3/sec. Between the measurements for 1639 and 1640 the foreline valve was closed (thus valving out the auxiliary mechanical pump), the leak detector was valved in, and the helium leak was valved in.)

Time (hr)	Chamber Pressure (μ Hg)	Output (divisions)	Leak Detector Pressure (μ Hg)
1640	5	15×1	0.04
1641	5	79×1	0.04
1642	5	31×5	0.04
1645	5	70×5	0.04
1650	5	66×10	0.04
1700	6	25×50	0.04
1715	6	40×50	0.04
1730	6	50×50	0.04
1825	7	77×50	0.04
1840	7	80×50	0.04
1900	7	86×50	0.04
1940	7	48×100	0.04

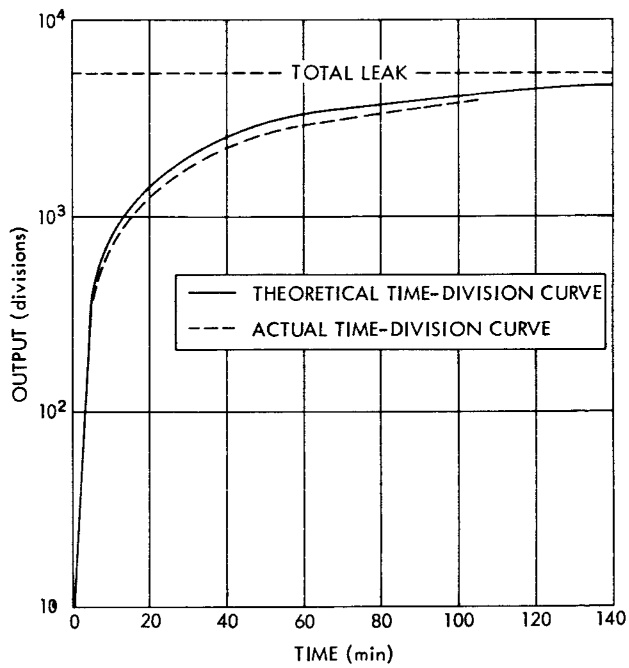

Figure B4—Detector output as a function of time.

speed can be obtained:

$$\frac{1}{C_{TOTAL}} = \frac{1}{C_{for\ 15'' \text{ of } 0.5'' \text{ i.d. line}}} + \frac{1}{C_{for\ 45'' \text{ of } 0.75'' \text{ i.d. line}}}$$

$$C = 1.9 \text{ ft}^3/\text{min} ,$$

and the effective speed is

$$S = \frac{\text{Leak Detector Speed} \times \text{Conductance}}{\text{Leak Detector Speed} + \text{Conductance}} ,$$

$$= 1.78 \text{ ft}^3/\text{min} .$$

From the effective system speed at the entrance to the chamber and the volume of the chamber, the response time can be calculated:

$$T = \frac{V}{S} = 64 \text{ min} .$$

This means that it will theoretically take 64 min. for the leak detector to indicate 63 percent of the 8×10^{-7} std cm^3/sec leak under the specified test conditions. By the use of Figure 1 in the body of the report, the theoretical curve may be drawn. A sample computation follows:

0.1 Time Constants = (0.1) (64 min) = 6.4 min
= 10 percent total deflection
= (0.1) (5300) = 530 divisions.

The results are very close. As might be expected, the theoretical time-division curve shows a slightly higher output for a given time. This is due to sorption and the slight helium dilution by air inbleed. The theoretical curve assumes a perfectly tight vacuum system with no outgassing.

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